1.0 EXECUTIVE SUMMARY

1.1 OVERVIEW

This report presents the findings of the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Inerting Harmonization Working Group (FTIHWG). The ARAC and its working groups cooperate to bring the expertise of the aviation industry, regulatory agencies, and public interest groups together to study specific subjects. The primary motivation of the FTIHWG is to save lives by enhancing airplane safety in an effective and practical manner.

The FAA tasked ARAC to provide a report recommending regulatory text and data needed by the FAA to evaluate options for new rulemaking requiring the elimination or significant reduction of flammable vapors through fuel tank inerting of transport-category airplanes. The FTIHWG studied several fuel tank inerting concepts. Fuel tank inerting is a method of reducing the oxygen concentration within fuel tanks to decrease the risk of explosions. Using methodology patterned after accepted FAA economic analysis practices, the FTIHWG found that none of these systems produced benefits, at present technology maturity levels, that were reasonably balanced by their costs.

The requested data is contained in this report. However, the FTIHWG is not recommending proposed regulatory text because this study was unable to identify any practical way of implementing the inerting designs studied.

Consequently, FTIHWG recommends that the FAA, NASA, and aviation industry conduct further research with an objective of developing more viable solutions for reducing fuel tank flammability much sooner than any of the inerting concepts evaluated could be implemented.

1.2 INTRODUCTION

The FTIHWG—the author of this report—has built upon the work of the 1998 Fuel Tank Harmonization Working Group (FTHWG), which assessed a broad range of methods to improve fuel tank safety through reduced flammability exposure. The FTHWG in its 1998 final report recommended that the FAA investigate further the feasibility of what it then identified as the two most promising methods:

- Directed ventilation.
- Fuel tank inerting.

The FAA chose to evaluate directed ventilation internally and tasked the ARAC with evaluating fuel tank inerting, leading to the formation of the FTIHWG. The FAA Tasking Statement requested that this HWG define and evaluate fuel tank inerting design concepts that would eliminate or significantly reduce the development of flammable vapors in fuel tanks. The FTIHWG was given 12 months to complete this assignment and prepare this final report.

Within this report is a comprehensive evaluation of the technical, safety, and economic merits of ground-based and onboard fuel tank inerting systems for in-service, current production, and new type design transport-category airplanes.

This ARAC study includes results of ongoing work being performed by the FAA under its internal fuel tank inerting research program. This FAA research covers the evaluation of the latest-available nitrogen generating technologies, research into fuel flammability, and various methods of inerting fuel tanks. Also covered in this report is the ground and flight-test program completed by the FAA and industry in early 2001, which provided essential data for this report.

1.3 SYSTEMS EVALUATED

The three basic inerting design system concepts addressed by the FTIHWG are

- Ground-Based Inerting (GBI)—a system using ground-based nitrogen gas supply equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to unheated wing tanks. The affected fuel tanks would be inerted once the airplane reaches the gate and is on the ground between flights.

- Onboard Ground-Inerting (OBGI)—an onboard system that uses nitrogen gas generating equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to an unheated wing tank. The affected fuel tanks will be inerted while the airplane is on the ground between flights.

- Onboard Inert Gas Generating System (OBIGGS)—a system that uses onboard nitrogen gas generating equipment to inert all the fuel system's tanks so that they remain inert throughout normal ground and typical flight operations.

In addition to these three basic design concepts, derivative combinations of OBGI and OBIGGS were also studied. They are described as "hybrid systems" in this report.

1.4 FTIHWG STRUCTURE

To manage and accomplish the requirements established by the FAA Tasking Statement, the FTIHWG established three primary task teams:

- Ground-Based Inerting Design (GBI).
- Airport Facilities (for GBI).
- Onboard Inerting Design (OBGI, OBIGGS, hybrid systems).

In addition, five support task teams were created:

- Airplane Operations and Maintenance.
- Estimating and Forecasting.
- Safety.
- Rulemaking.
- Integration.

1.5 SCOPE AND ASSUMPTIONS

The overall mission of the FTIHWG has been to determine whether safety enhancement through fuel tank inerting systems is practical. If not, this body was asked to propose research programs that would lead to a practical system.

The task teams included representatives from U.S. and non-U.S. companies from a variety of fields (e.g., commercial airlines, major and general aviation manufacturers, petroleum refiners, industrial gas suppliers, public interest groups). These experts worked closely to devise a practical inerting system.

As defined in the Tasking Statement, the FTIHWG based its work on the assumption that the proposed fuel tank inerting systems are not considered flight critical and, therefore, airplanes may be dispatched with the system inoperative. This assumption is fundamental to the technical and cost conclusions of this report.

For the purposes of this study, it was assumed that the resources would be made available as needed to implement a desirable inerting system. Further studies would be needed to assess the effect of the unavailability of industrial capacity, personnel, or any other resources needed to implement an inerting system.

During the study period, some 70 experts spent more than 50,000 hr evaluating a large number of fuel tank inerting options and design concepts together with the effects these systems would have if implemented in the existing fleet as well as airplanes yet to be designed. Areas specifically evaluated for resultant effects were safety (measured in the anticipated preclusion of future accidents), regulation, airplane configuration, airport infrastructure, and flight and maintenance operations. Underlying this exhaustive effort were a single defined set of *study ground rules* that were used by all participants to ensure that each team worked consistently and was aware of the requirements in all other areas.

When completed, the above efforts yielded a detailed body of knowledge that allowed the FTIHWG to draw informed conclusions based on data and analysis. These conclusions and recommendations specifically address the technical limitations of inerting, its potential benefits and hazards, and the relative costs of implementing inerting versus its projected benefits (i.e., cost-benefit analysis) as described below and in the body of this report.

1.6 TECHNICAL EVALUATIONS

Figure 1-1 summarizes the technical evaluation of each of the inerting system concepts considered by the FTIHWG.

1. Ground-Based Inerting (GBI)
Concept Center wing tanks (heated or unheated) and auxiliary fuel tanks are purged at the gate with nitrogen-enriched air (NEA) from an airport supply. Airplanes are equipped with a dedicated NEA service panel and manifold connected to a series of outlets inside the appropriate tank(s), thereby inerting the ullage (air space above the liquid fuel). Large transports take 30 minutes to inert, medium transports 25 minutes, and small transports 20 minutes. **Advantages** Simple, reliable, lightweight onboard equipment (tubes, etc.). Standard approach: every airplane supplied with NEA 1.7 times the maximum ullage volume. Service technician identifies airplane model and injects prescribed NEA volume. **Disadvantages** Dependent on dedicated airport supply system for NEA. Not inert after landing and until after ground servicing is completed. Ullage oxygen level increases during cruise, and—depending on initial fuel load—can exceed inert limits. Supply pressure varies by airplane type. Poses confined-space hazard to ground service personnel. New worldwide standard would be needed for interface and regulating equipment. Requires vent system changes for large portion of fleet. **Other issues** Dedicated, trained ground personnel needed. Impact on overall ground servicing operations (fuel, catering, baggage, cargo, etc.). Bigger impact will be on the airport infrastructure than on the airplane/airlines. Potential environmental issues from venting tanks overboard.
2. Onboard Ground Inerting (OBGI)
Concept Same as 1 above except airplane uses onboard equipment to generate NEA. Only operates on the ground. Time to inert a large transport: 60 minutes. **Advantages** Airplane is self-sufficient. A better solution for flights into airports with no airport NEA supply. **Disadvantages** Takes longer after landing to reach inert levels and may impact airplane turn time. Provides limited protection during flight cycle depending on flight duration. System is heavy, bulky, and requires external dedicated electrical power supply. System and component reliability is poor. Confined space hazard to ground support personnel. **Other issues** Air inlet and exhaust for compressor and heat exchangers require airplane hull penetrations. Pipes must be shrouded (double-walled pipes where they enter the pressure hull to prevent filling the cabin with nitrogen gas in the event of a leak). Introduces new hazard exposure (very small) to crew and passengers. Insufficient space to retrofit aboard most current in-service and new production airplanes.
3. Onboard Inert Gas Generating Systems (OBIGGS)
Concept Airplane uses onboard equipment to generate NEA. Operates throughout the flight, keeping the fuel tanks inert. **Advantages** Airplane is self-sufficient and thus not dependent on airports for NEA. Fuel tanks are actively inerted throughout ground and flight operations unless system is impacted by reliability. **Disadvantages** Demands more electrical power and high-pressure engine bleed air than is available on most airplanes. Weight and size aboard airplane much greater than for GBI. Draws exhausted cabin air as a source, increasing pressurization system maintenance burden. System and component reliability is poor. Introduces new hazard exposure to crew and passengers (very small). **Other issues** Shrouded pipes in the pressure hull. Mechanically very complex. Insufficient space available for installation aboard most in-service and current production airplanes.
4. Hybrid Systems
Concept These are variations of 2 and 3 that have been simplified in an effort to reduce weight, volume, power demands, and air consumption. Two systems are under consideration: • Hybrid OBGI system. • Hybrid OBIGGS (a scaled-down version of the full system). **Advantages** Smaller, lighter; less expensive than OBGI and OBIGGS. **Disadvantages** More time required to inert the fuel tanks; complex; limited system and component reliability; weight and space requirements for retrofit.

Figure 1-1. Technical Summary of Inerting System Concepts

1.7 TECHNICAL LIMITATIONS

The FTIHWG concluded that several major technical limitations and airport infrastructure obstacles must be overcome before a practical fuel tank inerting system could be implemented.

1. The technical limitations/airport infrastructure obstacles for GBI for in-service, in production, and new type design (i.e., future) airplanes are
   - Development and construction of fixed inerting equipment for large airports and medium-sized airports.
   - Development and production of mobile inerting vehicles.
   - Development of a worldwide industry standard for the nozzle, interface panel configuration, and control system that connects the airplane and inerting equipment to deliver the appropriate amount of nitrogen to the airplane fuel tank.
2. The technical limitations for OBGI and OBIGGS inerting systems on in-service and in-production airplanes are that they
   - Demand more engine/airplane bleed air to operate than is available.
   - May demand more airplane electrical power to operate than is available.
   - Take up more space (volume) than might be available on most airplane types (a problem that increases as airplane size decreases); appropriate locations may not exist.
   - Have components that demonstrate low reliability and high failure rates at current technology levels.
3. Future airplane types can be designed with adequate bleed air, electrical power, and volume for OBGI and OBIGGS systems, so the technical limitation of these inerting systems on future airplane types will be
   - The low-reliability/high failure rate of their current-technology components unless mitigated by the application of future technological breakthroughs.

1.8 BENEFITS

The benefit of a safety enhancement system like inerting is avoided accidents resulting in lives saved and prevention of airplane and property destruction. Analyses performed by the FTIHWG established the estimated levels of this potential benefit that fleetwide inerting would achieve.

For this study, six commercial airplane categories were defined and generic models were created with fuel system characteristics as closely representative as possible of today's in-service fleet and current production models. Figure 1-2 summarizes the fleetwide flammability exposure of these generic-study-category airplanes.

	Large transport, 275 passengers	**Medium transport, 195 passengers**	**Small transport, 117 passengers**	**Regional turbofan, 44 passengers**	**Regional turboprop, 31 passengers**	**Business jet, 7 passengers**
Baseline fuel tank flammability—no inerting system, %						
Unheated CWTs (no adjacent heat sources)	6.8	No unheated CWT	5.1	2.6	No CWT	No CWT
Heated CWT (with adjacent heat sources)	36.2	23.5	30.6	No HCWT	No HCWT	No HCWT
Main wing tanks	3.6	2.4	3.6	1.6	0.7	1.6
Fuel tank flammability—with an operative inerting system, %						
Ground-based inerting (heated CWTs)	4.9	2.0	5.2	No HCWT	No HCWT	No HCWT
Onboard ground inerting (heated CWTs)	7.0	1.4	5.8	No HCWT	No HCWT	No HCWT
Hybrid OBIGGS (heated CWTs)	0.9	0.6	0.3	No HCWT	No HCWT	No HCWT
OBIGGS (all tanks)	~0	~0	~0	NA	NA	NA

*Due to the estimated low reliability of these onboard systems, the fleet exposure when including inoperative systems would be 2% to 3% higher.

Figure 1-2. Flammability Exposure—Generic In-Service and Current Production Airplanes

Fleetwide flammability exposure is a measure of the percentage of the airplane operating hours during which the fuel tank analysis indicates a flammable fuel/air mixture would exist. A Monte Carlo–type simulation was used to estimate these percentages. The figure includes the estimated flammability exposure levels for current unmodified (baseline) and modified flammability percentages.

In estimating accidents avoided, the passenger counts for each of these six generic airplanes were derived based on the average number of passenger and crew seats for actual airplane type in that study category. This value was then factored by load factors (percentage of passenger seats expected to be filled) taken from the *FAA Aviation Forecasts Fiscal Years 2001-2012.*

Figure 1-3 shows the accidents anticipated to be avoided through implementation of each of the three basic inerting system design concepts. Avoided accidents are a function of the flammability exposure values and the number of hours flown by all airplanes in each of the generic airplane categories over the evaluation period. For the purpose of the cost-benefit study described below, a 16-year evaluation period was used. Although a 10-year evaluation period had been used in the 1998 ARAC study and the FAA ground-based inerting study, a 16-year period was chosen for this study because of the significant time that is required to design and achieve full fleet incorporation of these inerting system design concepts.

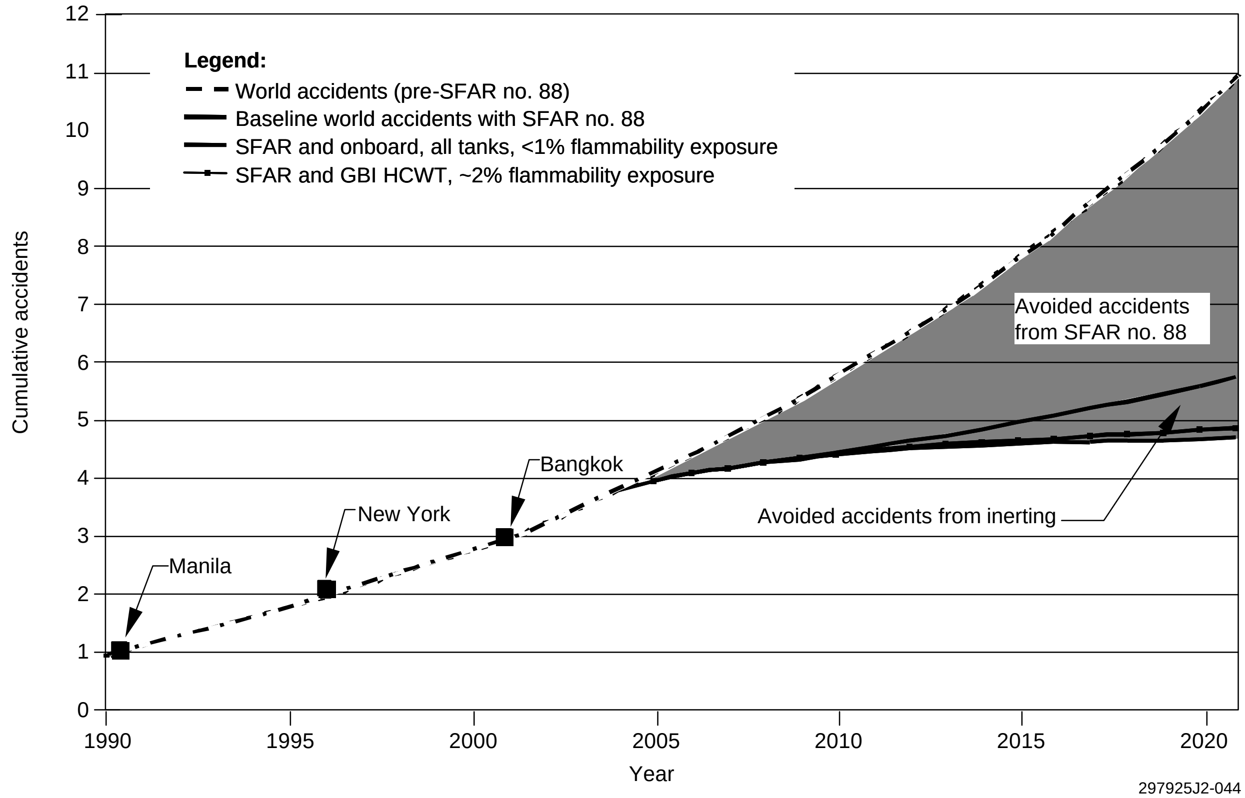


Figure 1-3. Worldwide Forecast Cumulative Accidents

The evaluation period begins in the first quarter of 2005 on the assumption that a rule change requiring fuel tank inerting would be effective at that time. Inerting systems for all applicable airplanes would be designed and certified by the first quarter of 2008 and all applicable airplanes would be modified by the first quarter of 2015. The evaluation period ends in the last quarter of 2020.

In figure 1-3 the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

The dotted line on figure 1-3 shows the estimated cumulative worldwide fuel tank explosion accident rate for a period 1990 through 2020. The three data points shown in the figure are actual accidents. The first two are confirmed to have resulted from fuel tank explosions while the third is suspected but has not yet been formally confirmed as such.

The estimated reduction in the accident rate resulting from SFAR no. 88 appears as a heavy black line. The third line down shows the further estimated improvement if a GBI system for inerting heated center wing tanks (CWT) were installed in the fleet. The fourth line down shows the estimated improvement if an OBIGGS system inerting all fuel tanks were adopted fleetwide. Thus, the estimated cumulative accident reductions attributable to GBI or OBIGGS are the difference between the SFAR line and those for GBI and OBIGGS.

The team evaluated accidents provided by the 1998 ARAC FTHWG study, plus the 2001 Bangkok accident, and agreed that the three most recent events (Manila 1990, New York 1996, and Bangkok 2001) should form the basis for statistically forecasting future events. These accidents each involved an explosion of the heated CWT, and the ignition source is unknown.

Figure 1-4 shows that the estimated number of avoided accidents with each inerting system design concept is approximately 1 accident (0.77 to 1.03) for the worldwide fleet in the 16-year evaluation period. Statistically, one fuel tank explosion in the 16-year evaluation period would result in approximately 1% of all fatalities from commercial airplane accidents forecast over that period. If these inerting system design concepts are fully implemented, after the implementation a ground-based system would likely prevent one fuel tank explosion in 10 years and an OBIGGS would likely prevent one fuel tank explosion in 8 years for the worldwide fleet.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Ground-based inerting (HCWT only)	0.24	0.9	0.54	No HCWT	No HCWT	No HCWT	0.87
Onboard ground inerting (HCWT only)	0.20	0.9	0.48	No HCWT	No HCWT	No HCWT	0.77
Hybrid OBIGGS (HCWT only)	0.24	0.9	0.58	No HCWT	No HCWT	No HCWT	0.91
OBIGGS (all tanks)	0.28	0.12	0.63	NA	NA	NA	1.03

Figure 1-4. Estimated Cumulative Worldwide Avoided Accidents, 2005 Through 2020

The estimated number of avoided accidents for the U.S. fleet (“N” registered airplanes) would be approximately 46% of the projected accidents avoided worldwide. It is estimated that for the same time period a ground-based design system concept would likely prevent one fuel tank explosion in 19 years and the OBIGGS would likely prevent one accident in 16 years for the U.S. fleet.

Based on this analysis, an estimate could be made of the expected number of lives that might be saved through prevented fuel tank explosions and postcrash fires during the evaluation period from 2005 to 2020. Using the above process, it is estimated that once either a GBI or OBIGGS system is fully implemented in the fleet, the accumulated fractional number of prevented fatalities over the 16-year evaluation period would be 132 for GBI and 253 for OBIGGS from in-flight and ground fuel tank explosions and postcrash fires.

1.9 HAZARDS

Nitrogen is a colorless, odorless, nontoxic gas that is impossible for human senses to detect when excessive concentrations displace the oxygen normally present in the air. Depending on the degree of oxygen depletion, the effects of breathing nitrogen-enriched air (NEA) range from decreased ability to perform tasks to loss of consciousness and death. Fuel tank inerting procedures would include stringent measures to minimize these hazards. The risks would exist wherever gaseous or cryogenic nitrogen is handled in the global aviation infrastructure.

The FTIHWG lacks the expertise to assess these risks with confidence. However, a simple extrapolation of available data from the Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) would suggest a rate of 1.4 to 4.7 fatalities per year worldwide. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that from 24 to 81 lives may be lost over the 2005–2020 study period as a result of this hazard.

1.10 COST-BENEFIT ANALYSIS

Figure 1-5 shows the present value estimate of inerting system total costs and monetary value of the benefits gained by introducing each of the three basic inerting design system concepts. The benefits were calculated by multiplying the annual number of avoided accidents (presented as fractional values) by the accident cost and then discounting these values by a net discount rate of 7% to the year 2005, which is the beginning of the evaluation period. The accident costs were estimated using established Department of Transportation (DOT) values. The benefits also include the monetary value of lives saved in postcrash fires. They do not include the cost of lives lost due to the hazards of inerting. The total cost for each inerting system includes the cost for in-service, current production, and new type design airplanes. There is little difference in cost between in-service and current production airplanes, except for the 20% to 30% higher installation costs for the retrofit airplanes and the associated airplane downtime. Also, with today's technology, there is little difference in the cost between current production and new type design airplanes.

	Benefits ($US billion)	Cost ($US billion)	Cost-benefit ratio
GBI (HCWT only)	0.245	10.37	42.3:1
OBGI (HCWT only)	0.219	11.60	52.9:1
Hybrid OBIGGS (HCWT only)	0.257	9.90	38.5:1
OBIGGS (all tanks)	0.441	20.78	47.1:1

Figure 1-5. Cost-Benefit Analysis Results, Worldwide Fleet, 2005 Through 2020, Based on Present Value in Year 2005 $US

The benefits shown in figure 1-5 have been calculated on the basis of a 75% reduction in projected fuel tank explosions due to SFAR no. 88. If the actual reduction in fuel tank explosions due to SFAR no. 88 proves to be less than 75%, then the benefits from inerting would be proportionally greater, and vice versa.

1.11 OVERALL CONCLUSION

The FTIHWG has concluded that the current technology of GBI, OBGI, and OBIGGS cannot meet the desired evaluation criteria for a fuel tank inerting system. This conclusion was reached collaboratively by many involved aviation and industry experts who, after intensive efforts, could not devise a practical, timely, and cost-effective method of proposing a fuel tank inerting design concept as a viable solution based on the Tasking Statement guidelines.

The FAA Tasking Statement for this ARAC FTIHWG study requested that this Working Group provide recommended regulatory text for new rulemaking based on the lowest flammability level that could be achieved by an inerting system design concept that would meet the FAA regulatory evaluation requirements. These evaluation requirements include a cost-benefit analysis similar to the analysis performed in this study. Because this study was unable to identify any practical way of implementing the inerting design concepts studied, the FTIHWG concluded that they could not recommend regulatory text based on the flammability level of an inerting system.

The FTIHWG also concluded that if a GBI system is considered for implementation, it will be necessary, before promulgating an airplane requirement, to resolve the current lack of global regulatory authority and industry control over the introduction and construction of new airport inerting supply systems, fixed or mobile.

Consequently, this FTIHWG has also concluded that the FAA, NASA, and the industry must continue to work cooperatively to research methods to reduce fuel tank flammability exposure that can be introduced much sooner than any of the inerting concepts. They should also pursue further basic research into technical breakthroughs in fuel tank inerting system design concepts as well as alternative concepts to improve the fuel tank safety of existing and future airplane designs.

1.12 RECOMMENDATIONS

The ARAC FTIHWG specifically recommends the following actions to be expeditiously carried out by the FAA, NASA, and the industry:

Inerting Systems

- Continue to evaluate and, where appropriate, investigate means to achieve a practical onboard fuel tank inerting system design concept for future new type design airplanes.
- Pursue technological advancements that would result in onboard fuel tank inerting designs having decreased complexity, size, weight, and electrical power requirements, and increased efficiency, reliability, and maintainability.
- Perform NEA membrane research to improve the efficiency and performance of membranes resulting in lower non-recurring costs of NEA membrane air-separation systems. For example, basic polymer research to increase the operational temperature of membranes to a level above 302°F.
- Conduct basic research into high-efficiency, vacuum-jacketed heat exchangers, and lighter, more efficient cryogenic refrigerators for use in inerting systems.
- If a practical means of achieving a cost-beneficial fuel tank inerting system is found, establish a corresponding minimum flammability level and reevaluate and propose regulatory texts and guidance materials accordingly.

Fuel Tank Flammability

- Evaluate means to reduce fuel tank flammability based on existing (e.g., directed ventilation, insulation) or new technology that might be introduced sooner into the in-service fleet and current airplane production.
- Initiate a project to improve and substantiate current flammability and ignitability analyses to better predict when airplane fuel tank ullage mixtures are flammable. This research is needed to support informed design decisions and rulemaking.
- Initiate a project to thoroughly document and substantiate the flammability model used in this study.

1.0 EXECUTIVE SUMMARY ADDENDUM

At the August 8, 2001 ARAC Executive Committee meeting the FTIHWG was asked to include additional information in this report. The requested information is included within this addendum to the Executive Summary. This addendum includes: a) a summary of the cost-benefit sensitivity analysis, b) the letter written by the FAA's representative to the FTIHWG co-chairmen, c) the FTIHWG co-chairmen's response to the FAA letter and d) questions from the ARAC Executive Committee members and the FTIHWG's responses.

Summary of the Cost-Benefit Sensitivity Analysis

After the June 2001 report was finalized, the FAA's Working Group member sent a letter to the Co-Chairs of the Working Group requesting that certain previously raised FAA questions about some of the assumptions used in the study be documented in the report. To address those concerns, the working group conducted a sensitivity analysis to evaluate the effects of changing some assumptions. This analysis evaluated the effects of: SFAR 88 benefits, labor hours and productivity, number of airports with an inerting systems installed, airplane operational data, delay costs, retrofit implementation and ground vs in-flight accident rates. The sensitivity analysis was conducted on the Ground Based Inerting (GBI) and the hybrid On-Board Inert Gas Generating System (OBIGGS) system. For the GBI system, the Net Present Value (NPV) costs to US operators ranged from \$4.2 Billion (\$US) to \$5.0 Billion. The Benefits ranged from \$69 Million to \$282 Million. For the hybrid OBIGGS system, the NPV cost to US operators ranged from \$3.7 Billion to \$4.4 Billion. The benefits ranged from \$73 Million to \$300 Million. None of these results were sufficient to change the working group's conclusions or recommendations.

Additional effects that were not considered in the sensitivity analysis: selective ground based inerting (decreases costs), flight cancellation costs (increases cost), cost of gate turn-time increases (increases cost), cost of no MMEL relief (increases cost), airport equipment depreciation and replacement costs (increases cost), airline spare parts provisioning costs (increases cost), value of lives lost in inerting accidents (decreases benefits).

Baseline assumptions for GBI assume that SFAR 88 changes are fully implemented by 2007 and give a 75% reduction in accident rate (value from 1998 ARAC and the lower of the two values proposed in the SFAR NPRM). The cost of ground operations assumes that dedicated personnel accomplish the inerting process and that large airplanes take 30 minutes, medium airplanes take 25 minutes and small airplanes take 20 minutes to inert. The baseline case assumes that the inerting labor is 100% efficient, that is, there is no idle time for the inerting crews. It assumes that all B, C and D airports would get some form of an inerting system. The airplane operational costs use the weight penalty developed in the 1998 ARAC study, which accounts for weight and fuel volume limited take-offs. The operational costs also assume that the cost of the first 30 minutes of each delay is discounted. The baseline implementation plan assumes that 70% of retrofits are done during a heavy check. The baseline benefit calculation assumes that 15% of the future accidents occur on the ground (this is consistent with calculated flammability exposure time). With these assumptions, the baseline NPV cost to US operators is \$4.8 Billion and the benefit is \$95 Million for a cost-benefit ratio of 50:1.

The first sensitivity case evaluates the effects making the following assumptions:
Assume that SFAR 88 changes are delayed until 2010 and are only 25 percent effective in reducing fuel tank accidents. Assume that it only takes 10 minutes per airplane to accomplish

inerting at large and medium airports and $10 per airplane to accomplish inerting at small airports (values proposed in an FAA study). Assume that inerting equipment is installed only at airports currently serviced by airplanes with 100 passengers or more (175 fewer airports than the baseline case). Assume that there are no weight or fuel volume limited take-offs. The combination of these assumptions lowers the NPV cost to $4.2 Billion and increases the benefit to $282 Million for a cost-benefit ratio of 15:1. **Figure 1** shows the baseline costs and benefit compared to these adjusted values.

The second sensitivity case evaluates the effects of making the following assumptions: Assume that SFAR changes are implemented by 2007 (baseline) and these changes reduce the accident rate by 90% (high value used in SFAR 88 NPRM). Assume that the labor productivity for the inerting personnel is to 70%. Assume that the full delay costs (per ATA study) are incurred. Assume that 70% of the retrofits are accomplished outside of a heavy check. Assume that 1 out of 3 future accidents occur on the ground (historical rate). These assumptions increase the NPV cost to $5.0 Billion and the decrease the benefit $69 Million for a cost-benefit ratio of 73:1. **Figure 2** shows the baseline costs and benefit compared to these adjusted values.

The baseline Assumptions for Hybrid OBIGGS are as follows: Assume that the SFAR 88 changes are fully implemented by 2007 and give a 75% reduction in accident rate (value from 1998 ARAC and the lower of the two values in the SFAR NPRM). Apply the weight penalty developed in 1998 ARAC study, which accounts for weight and fuel volume limited take-offs. Assume that the first 30 minutes of each delay is not discounted. Assume that 70% of retrofits are done during a heavy check. Assume that 15% of the future accidents occur on the ground (this is consistent with calculated flammability exposure time). These assumptions give a baseline cost of $4.16 Billion for US operators and a benefit of $101 Million, for a cost-benefit ratio of 41:1.

The third sensitivity case evaluates the effects of making the following assumptions: Assume that the benefits of full implementation of SFAR 88 delayed until 2010, and only 25 percent effective in reducing fuel tank accidents. Assume that there is no weight or fuel volume limited take-offs. The combination of these assumptions lowers the NPV cost to $3.7 Billion and increased the benefit to $300 Million for a cost-benefit ratio of 12:1. **Figure 3** shows the baseline costs and benefit compared to these adjusted values.

The fourth sensitivity case evaluates the effects of making the following assumptions: Assume SFAR 88 changes are implemented by 2007 (baseline) and these changes reduce the accident rate by 90% (high value used in SFAR 88 NPRM). Use the full delay costs per ATA study. Assume that 70% of the retrofits are accomplished outside of a heavy check. Assume that 1 out of 3 future accidents occur on the ground (historical rate). These assumptions increase the cost to $4.46 Billion and decrease the benefit to $73 Million for a cost-benefit ratio of 61:1. **Figure 4** shows the baseline costs and benefit compared to these adjusted values.

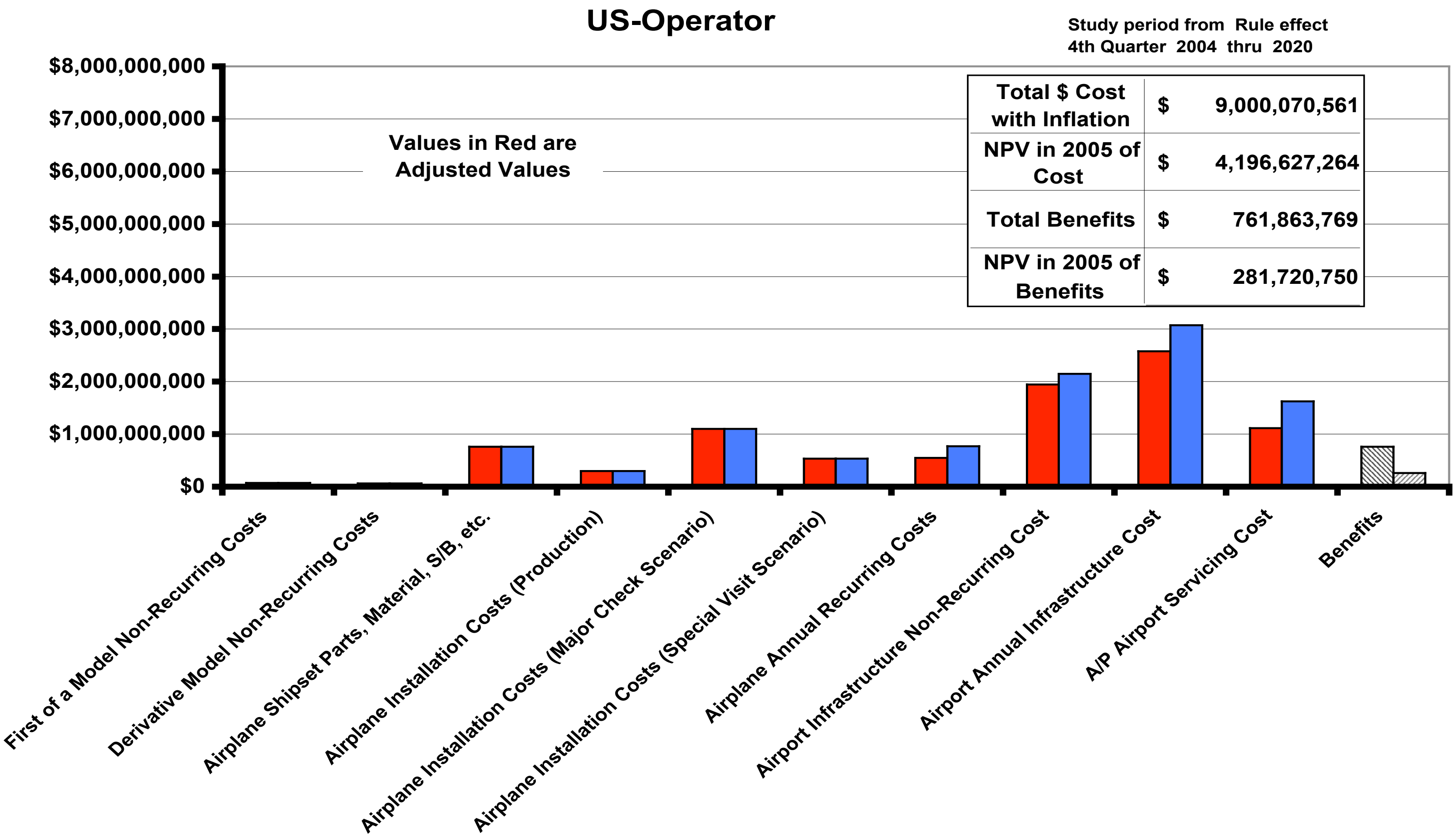
SENSITIVITY ANALYSIS CONCLUSIONS

Every attempt was made to fairly represent the technical requirements, estimated costs and safety benefits, and regulatory matters. The baseline cost-benefit analysis represents a balanced approach to the uncertainties in the study assumptions.

Cost Benefit Ratio
Decreased to 15:1

Figure 1
Sensitivity Analysis

Scenario 11 - Ground Based Inerting HCWT only, All Transports

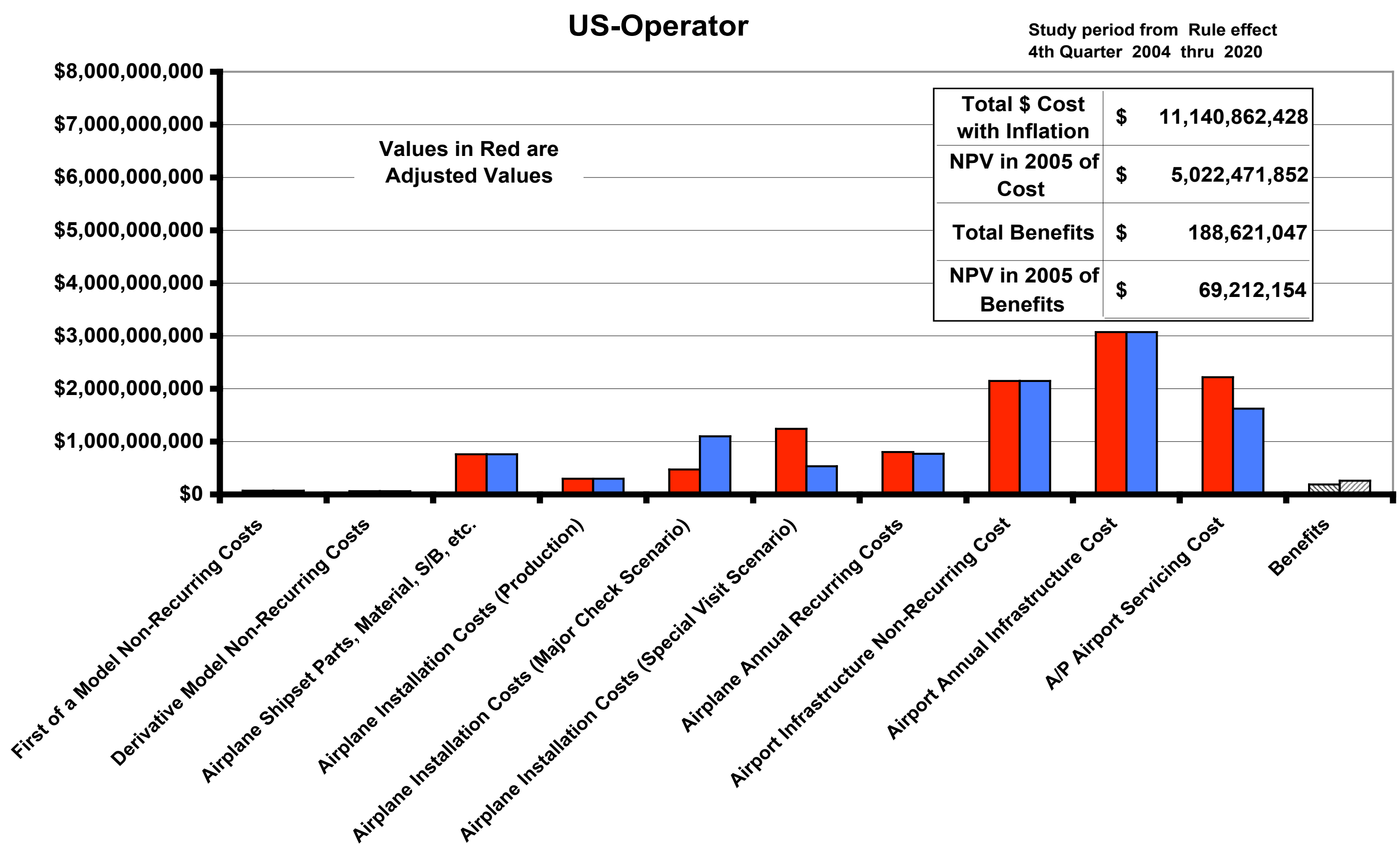


Total $ Cost with Inflation	$	9,000,070,561
NPV in 2005 of Cost	$	4,196,627,264
Total Benefits	$	761,863,769
NPV in 2005 of Benefits	$	281,720,750

Cost Benefit Ratio
increased to 73:1

Figure 2
Sensitivity Analysis

Scenario 11 - Ground Based Inerting HCWT only, All Transports



Total $ Cost with Inflation	$	11,140,862,428
NPV in 2005 of Cost	$	5,022,471,852
Total Benefits	$	188,621,047
NPV in 2005 of Benefits	$	69,212,154

Cost Benefit Ratio
decreased to 12:1

Figure 3
Sensitivity Analysis

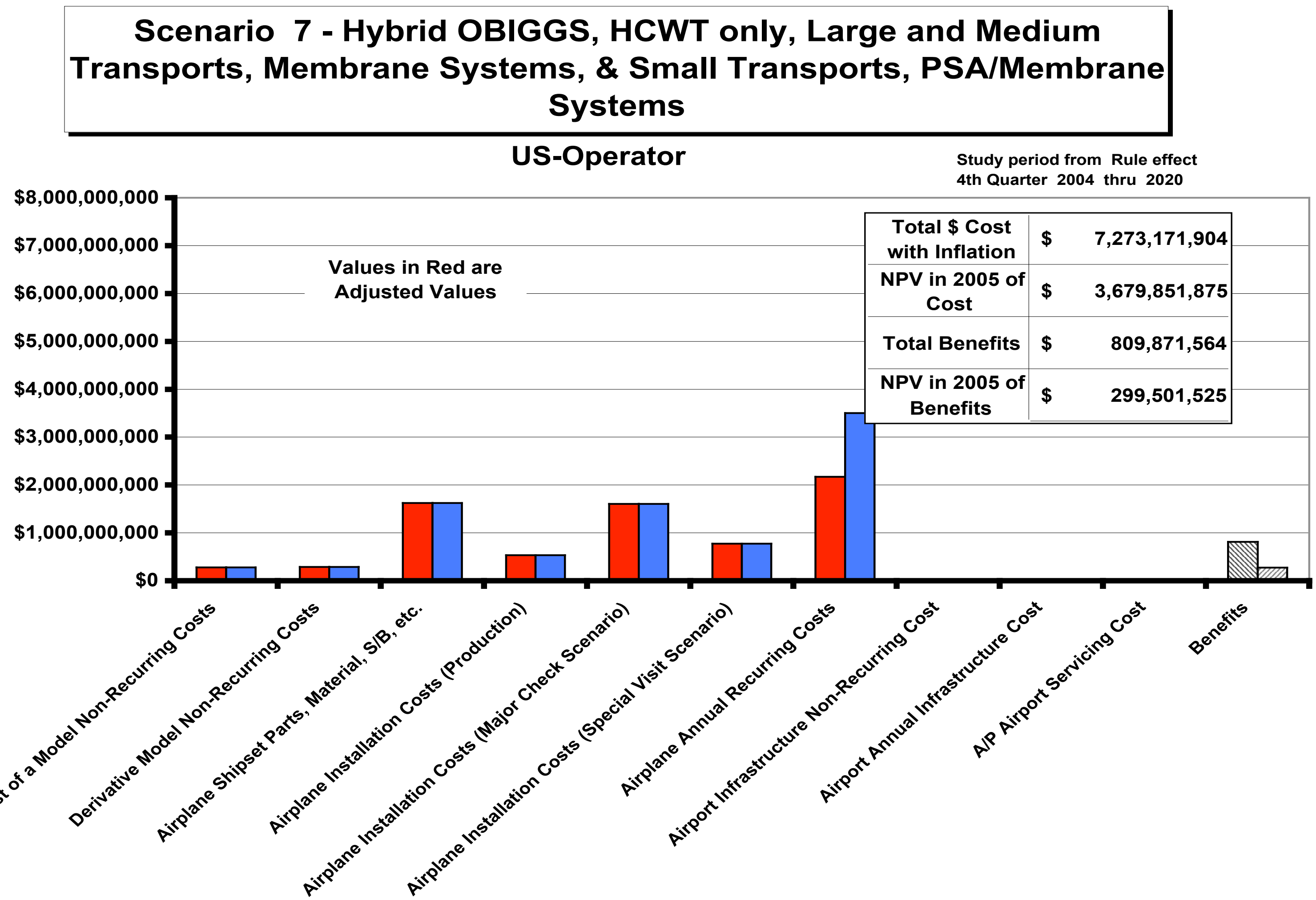


Figure 4
Sensitivity Analysis

Cost Benefit Ratio
increased to 61:1

Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems, & Small Transports, PSA/Membrane Systems